



Magnetized water as an alternative strategy to improve the poultry production system

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ABSTRACT

There is a demand for new alternative strategies to improve the health and production of poultry. One of these approaches is the magnetization of the drinking water. Therefore, this review discussed the different effects of magnetized water on poultry production traits, carcass traits, immune response, antimicrobial activity, blood parameters, and oxidative stress. Exposure of water to diverse magnetic fields positively rearranges the chemical structure and consequently improves its quality. Broilers that received magnetized water showed an improvement in the body weight gain and feed conversion ratio. Layers revealed an increase in egg quantity and quality, and breeders exhibited a rise in the fertility and hatchability parameters. Improvement of the dressing and carcass traits has been shown after providing magnetized water. Moreover, magnetized water may enhance humoral immunity, decrease the pathogenic microbial load, and increase the beneficial bacterial populations. Amelioration in the liver and kidney enzymes and other blood parameters as well as relieving of oxidative stress were also detected in birds supplied with magnetized water. In conclusion, further research in this area and also more encouragement of poultry farmers to treat birds with magnetized water are recommended.

Keywords

antimicrobial, immunity, magnetized water, oxidative stress, production

Number of Figures: 1
Number of Tables: 1
Number of References: 65
Number of Pages: 10

Abbreviations

*E. coli: Escherichia coli
Ig: Immunoglobulin
ND: Newcastle disease
HDL: High-density lipoprotein*

*LDL: Low-density lipoprotein
ALT: alanine aminotransferase
AST: aspartate aminotransferase*

Introduction

The fast-growing poultry industry prohibited the use of antimicrobial growth promoters during the production period to avoid the development of antibiotic-resistant pathogens that affect poultry flock health and performance. These changes necessitate the search for alternatives in the poultry production system [1]. Poultry flock performance is affected by the quality of water provided to birds. Improper cleaning and disinfection of water lines and pipes in poultry farms result in the increased risk of water contamination which adversely affects the health and production of birds [2]. Several pathogenic bacteria, such as *Salmonella*, *E. coli*, *Pseudomonas*, *Proteus*, *Klebsiella*, *Shigella*, *Vibrio*, *Staphylococci*, and *Streptococci* species, as well as fungi, including *Aspergillus*, *Penicillium*, and *Mucor* species, have been isolated from the drinking water in poultry farms [3-6].

In addition, using underground water in the poultry farms of some developing countries represents a major challenge. The suitability of water for poultry consumption is affected by total dissolved salts, salinity, nitrates [7], and excessive concentrations of inorganic ions, such as Ca^{+2} , Mg^{+2} , Na^{+} , Cl^{-} , SO_4^{2-} , and HCO_3^{-} in water [8]. Different techniques have been applied to improve water quality, one of which involves using magnetic forces to magnetize water. Magnetized technology depends mainly on moving electric charge in the ionized form and the magnetic field [9]. For several decades, magnetized water has been used in several sectors such as agriculture, industry, medicine, environment, and veterinary practice.

Various biological characteristics could be detected after magnetizing the natural water. Magnetization of water restores natural energy [10] and increases electrical conductivity and dielectric constant which consequently improves the water quality [11, 12]. Furthermore, a magnetic field enhances the formation of a beneficial structure, raises fluidity and hydroxyl alkaline ions [13], reduces acidity, and forms alkaline molecules [14]. Magnetization costs less than other chemical and physical water treatments. In addition, it could augment the dissolving capacity for vitamins and minerals [15], leading to facilitated nutrient transfer across cell membranes, uptake, and utilization [16, 17].

The different effects of using magnetized water on the poultry production system are summarized in Figure 1. Many investigations with controversial results have been performed in different countries to evaluate the impact of magnetized drinking water on poultry production. Therefore, this review aimed to discuss the different effects of magnetized water on poultry production traits, carcass traits, immune response, antimicrobial activity, blood parameters, and

oxidative stress.

Mechanism of water magnetization in poultry farms

Water is a paramagnetic element in which some or most of its single atoms, ions, or molecules have a constant magnetic dipole moment. Water magnetization can be achieved by passing water through magnetic tubes or putting a constant neodymium disc magnetic device (modifier) in water. The magnet may be neodymium, iron, or boron, and is coated with an epoxy-nickel-copper-nickel for the effective protection of the magnet against corrosion and acidic conditions. The number of magnets (funnel), the shape of magnets (liner or circle), and the diameter and thickness of magnets that create the magnetic field vary according to the manufacturer's instructions. The unit of measuring magnetic fields is teslas or gauss as one tesla is equal to 10,000 gauss. The magnetic field strength is also variable. Water is usually passed through a magnetic funnel at a relatively low speed to prevent water overflow and then, it is collected into graduated cylinders for distribution. Next, the purified water is circulated in a closed loop from a closed tank through a tubing system linked to a pump. Therefore, a solution can pass through the field many times in a closed cycle. The incubation period is usually several hours and the memory of magnetic treatment extends beyond 200 h. However, water usually retains the magnetic characteristics for 6-12 h following water passage through the magnetic field of the funnel. Because of decreasing the magnetization of water over time, the magnetization process may be repeated. Magnetized water, particularly with high gauss (more than 1000 gauss/month), can improve health, immunity, growth of broilers, and some egg production traits of hens.

The molecules of regular tap water are not separated from each other and form clusters due to the presence of hydrogen bonds. When tap water passes through a stable magnetic field, the size of clusters and the number of grouped molecules decline. Consequently, the activity of water molecules rises with better bioavailability and absorption into the cell's membranes. A magnetic field can enhance water purification and affect both the physical and chemical processes of water dissolution and crystallization. Accordingly, some positive changes in water characteristics, such as increasing the oxygen ratio, water viscosity, water salinity, and velocity of dissolved salts and amino acids may be detected. Augmenting the ratio of dissolved oxygen is attributed to decreasing the organic matter content in magnetized water. However, water salinity rises due to increased soluble salts. Other physical properties of water, such as increasing the pH, conductivity, evaporating temperature, minerals,

and organic matter, as well as reducing total bacterial count can be detected after magnetization of water. As a result of the diminished tension of magnetized water surface by 10%-12% with increasing velocity, the water penetration and diffusion into the cell wall could be facilitated and accelerated. Moreover, it has been indicated that more hydroxyl (OH^{-}) ions are created, forming alkaline molecules and decreasing water acidity. Therefore, both the electric conductivity and dielectric constant of water will increase. Normal water has a pH of about 7, while magnetized water may show a pH of 9.2 after exposure to a 7000 gauss strength magnet for a long time. All of these effects depended on the power of the magnetized field and the duration of exposure to this field.

Effects of magnetized water on the poultry production system

The different effects of magnetized water on the production system are summarized in Table 1.

Production traits**Broilers**

Water magnetization induces significant improvement in water quality which consequently reflects the production performance parameters of broilers [18, 19]. Broilers that received magnetized water showed a shorter growing period, enhanced growth rate, improved meat quality [20], and lower mortality [21]. A significant increase in the broiler body weight was observed in day-old broiler chicks treated with magnetized water for 5 weeks compared to control non-treated chickens [22-24]. In addition, magnetized water significantly enhanced body weight, weight gain, and feed efficiency during 1-35 days of age [25].

The type of feed ingredient, processing, solution, water magnetization, and ambient temperature are key factors for the acid-binding capacity of feed stuff and pH, which cause a well-known effect on the absorption of some nutrients in the intestine [26]. El-Hanoun et al. [27] demonstrated that magnetized tap water could improve the body weight and feed conversion ratio of broiler geese compared to the well water provided group. In addition, improved performance was detected in gosling's progeny which indicated a long-term carryover effect of magnetized water and magnetization on progeny performance [27]. Enhanced final body weight (7.3%), daily weight gain (7.4%), feed conversion ratio (11.7%), protein efficiency ratio (23.3%), and production index (20.6%) were reported in broiler chicks that received magnetized water [28].

Magnetization of water induces many positive changes in water quality via rearranging cations/an-

ions in a new format in the media [19]. Increasing the concentration of oxygen and the solubility of minerals hasten the transfer of water and nutrients in the body's compartments and enhances the growth of cells. As a result, the permeability of the cell wall will be improved and the surface tension and electric conductivity will decrease [29-31]. Furthermore, magnetic treatment of water could enhance the health status of animals by reducing lime deposition and microbial load in water pipes [32].

On the other hand, some studies showed no effect of magnetized water supplementation on broilers' performance. Al-Mufarrej et al. [18] found no significant effect of magnetized water on the feed intake, feed conversion ratio, and body weight gain of broiler chickens. Cai et al. [33] demonstrated that broiler chickens fed on magnetized water showed diminished feed consumption and increased feed conversion ratio. Moreover, the performance and health of guinea fowl were not affected by magnetized drinking water [34]. Water magnetization at 500 gauss with 5, 10, and 15 min exposure time induced no significant differences in the mortality rate, feed intake, body weight, weight gain, feed conversion ratio, performance index, and viability of broiler chicks [35, 36].

The inconsistent results regarding the effect of magnetized water on broilers' production performance might be related to various factors, including the differences in the magnetic field strengths, duration of water passing through the magnetized device, mineral content, and cleanliness of water before passing through the magnetic device [36].

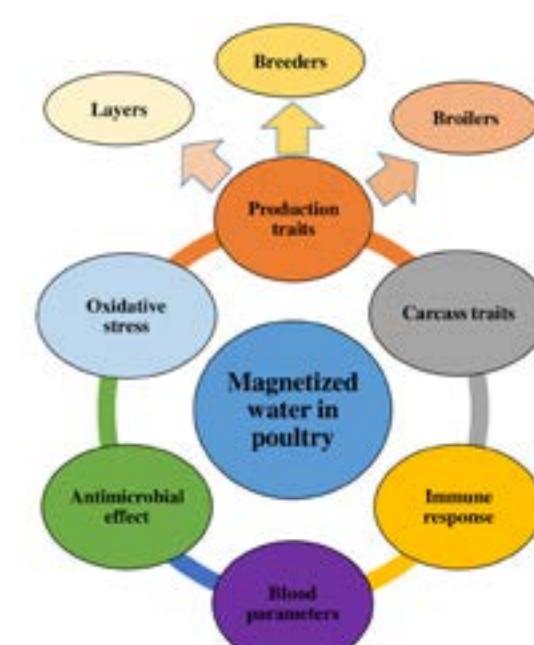


Figure 1.
The different effects of using magnetized water on the poultry production system

Table 1.

The different effects of magnetized water on production system of poultry.

Water treatment	Findings	References
Magnetized water (500 gauss) for 1-32-days-old broilers	- Decreased water consumption without influence on performance, carcass composition, and immune response. - Non-significant reduction in performance between sexes.	18
Magnetized water (6000 gauss) for broiler chickens	- Reduced mortality. - Increased feed conversion coefficient, performance efficiency factor, European production efficiency factor, and livability.	24
Magnetized water (85-102 tesla in a rate of 10 hrs/day) for 1-42-days-old broilers	- Increased growth performance, immune response, and lactic acid producing bacteria. - Reduced total bacterial and coliform counts.	28
Magnetized water (500 gauss for 5, 10, and 15 min) for 42-days-old broilers	- Improvement of productive traits (body weight, weight gain, feed intake, feed conversion ratio, mortality, viability, and production index)	35
Magnetized water (1850 gauss) for 42-days-old broilers	- No influence on feed conversion ratio, body weight gain, feed intake, and livability.	36
Magnetized water (500 gauss with different speed flow) for 1-42-days-old broilers	- Improved final body weight, daily gain, feed conversion ratio, protein efficiency ratio, and performance index, but decreased total feed intake. - Improved total protein, globulin serum concentration, antibody titer production, immune organs relative weights, improved liver functions, and dressing percent. - Reduced total intestinal bacterial and coliforms counts, but increased lactic acid count.	44
Magnetized water (more than 1000 gauss/month) for boilers and layers	- Improved immunity and growth (approximately +4 % in weight) for broilers. - Enhanced eggshell thickness (approximately +9 %) for hens.	45
Magnetized water (6 hrs/ day for 9 weeks) for day-old Pekin ducklings	- Improved feed conversion ratio, protein efficiency ratio, production index, and phagocytic activity. - Increased viscosity of the ileal content and intestinal villi length.	48
Magnetized water (13.200 gauss/6 hrs/ day) from 5-35 days of age	- Maintaining viability of the ND virus vaccine titer for 4 hrs, but minimizing <i>E. coli</i> and <i>S. Typhimurium</i> survival. - Increased performance traits, carcass and immune organ weights, total <i>Lactobacillus</i> count, and sera Ig concentrations. - Reduced stress markers and total bacterial and enterobacteriaceae counts.	49
Magnetized water every 6 hrs with acidifier 4m/liter for 1-35-days-old broilers	- Enhanced growth performance, immune response, intestinal health, and absorptive capacity.	50
Magnetized water (5 μ Tesla rms/ 30 min/ day) for 1-35 days-old broilers	- Protection from <i>E. acervulina</i> , <i>E. maxima</i> , and <i>E. tenella</i> infestation	53
Magnetized water (1000 gauss discharge 1000 liters/hr) for 36-days-old broilers	- Low blood sugar, cholesterol, and triglyceride	54
Magnetized water (500 or 1000 gauss for 60 days) for Japanese quail	- Increasing red blood cells, white blood cells, haemoglobin, packed cell volume percentage, total protein levels, alkaline phosphatase activity, and mitotic index. - Reduced total cholesterol, LDL, triglycerides, glutathione, and glucose levels.	56
Magnetized water every 12 hrs for 56-days-old broilers	- Improved final body weight, daily body weight gain, total body weight gain values, and feed conversion ratio.	61
Magnetized water (4000 gauss for 28 weeks) for one-year-old Egyptian geese	- Improved body weight, feed conversion ratio, and renal and hepatic functions. - Increased production, quality and hatchability of eggs, levels of reproductive hormones, and antioxidant in blood.	27
Magnetized water (3000 gauss) for 48-weeks-old laying hens for 2 months	- Improved internal egg quality characteristics, shell mass, and egg: feed efficiency. - No influence on egg numbers and egg mass.	37
Magnetized water (2000, 3000, and 4000 gauss) for 28-week-old laying hens	- Improved feed consumption, feed conversion ratio, eggs weight and mass, shell thickness, and albumen, albumen dry matter, and yolk percentages. - Increased red blood cell count, haemoglobin, serum phosphorus level, blood pH, and triiodothyronine. - Decreasing albumin/ globulin ratio.	38
Magnetized water (0.65 tesla) for 32-weeks-old laying hens	- The limestone crystals tended to be larger and more uniform in size with increased egg strength.	41
Magnetized water (4000 or 6000 gauss) for one-year-old geese	- Improved semen quality, reproductive traits, functions of kidney and liver, antioxidant status, and immune response.	46

Table 1 cont.

Magnetized water (4000 gauss) for rabbit bucks	- Increasing body weight, feed intake, reaction time, fertility, sperm concentration, mass motility, total live sperm, testosterone hormone, IgA, and antioxidant enzymes. - Decreasing lipid peroxidation biomarker malondialdehyde and thiobarbituric acid-reactive substances.	17
Magnetized water (4000 gauss) for weaning rabbits	- Improved body weight, body weight gain, feed conversion ratio, and feed intake. - Increasing red blood cells counts, hemoglobin concentration, packed cells volume, and white blood cells count. - High lymphocyte and monocyte percentages, IgG, IgM, and IgA, plasma total protein, and globulin concentrations - Low neutrophil, eosinophils, and basophils percentages, plasma total lipid, cholesterol creatinine, aspartate amino transferase, and alanine amino transferase concentrations.	47
Magnetized water (1200 and 3600 gauss for 30 days) for 6-weeks-old rabbits	- Improved productive performance and functions of liver and kidneys	52
Magnetized water (450 to 500 gauss) for Zealand albino rabbits	- Improved oxygenated hemoglobin derivative-oxyhemoglobin. - Decreased oxidized form of hemoglobin (methemoglobin).	59

Layers

Magnetic water treatment is now widely used in poultry farms to enhance the production performance of layer chickens [14, 37]. Gimmizah layer chickens that received 2000, 3000, and 4000 gauss of magnetized water showed higher feed intake, better feed conversion ratio, and an increase in egg weight, shell thickness, yolk, albumin percentage, and albumin dry matter compared to the non-treated control birds [38]. The authors attributed these positive effects on the performance and egg quality to the higher levels of triiodothyronine induced by magnetic water treatment. Studies by Roland and Harms [39] and Verma [40] revealed that magnetized water may help in increasing calcium solubility and its precipitation in bones when egg shell calcification occurs. Moreover, egg shell quality may enhance due to the potential influence of water magnetization on the availability of calcium carbonate and consequently the strength of the egg shell [41].

Breeders

Mustafa and Hassani [42] observed improved production traits, egg quality, and survival rate in breeder chickens after magnetizing water in summer. Furthermore, fertility, egg quantity, quality, hatchability, and levels of reproductive hormones, such as progesterone and estrogen increased in geese treated with magnetized water in comparison with birds supplied with well water [27]. Roosters that drank magnetic water revealed more improvement in semen quantity and quality than those that received tap water [43].

Carcass traits

El-Hanoun et al. [27] indicated that treating well

water with a magnetic field induced great positive effects by increasing the percentage of dressed carcass and skin but decreased the abdominal fat of geese that received this water. Moreover, Soltan et al. [44] showed that magnetized water treatment significantly raised the dressing percentage of broilers, but had no significant effect on the other carcass traits. However, no significant influence of magnetized water on the broilers carcass weight, thigh, drumstick, breast, back, neck, and abdominal fat has been reported [18]. The weight and length of the intestinal tract increased in broiler chickens treated with magnetized water for 42 days as a result of augmented villus height and muscle thickness of the jejunum [36].

Immune response

Water subjected to a magnetic field of over 1000 gauss could improve the birds' health and immunity [45]. Magnetization of water with a 6000 gauss magnetic field significantly increased the levels of serum IgG, IgM, and IgA in Egyptian male geese [46]. Similarly, treatment of water with 4000 gauss significantly raised the concentrations of IgG, IgM, and IgA in rabbits [47]. El-Katcha et al. [48] concluded that magnetic water and some additives significantly improved the phagocytosis of Pekin ducklings compared to controls. Recently, Soliman et al. [49] reported a significant rise in the total IgG and IgM against live ND virus vaccination after the treatment of broiler chickens with magnetized water. In addition, magnetized water significantly enhanced antibody titers against live ND virus vaccine in broiler chickens infected with *Salmonella enteritidis* [50]. Contradictory results showed that the exposure of water to a magnetic field did not influence antibody responses to sheep red blood cell antigens in broiler chickens [18]. Moreover, an in vi-

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tro study showed a significant reduction in ND virus vaccine titer administered in water, saline, and magnetic water at levels of 94.13%, 84.53%, and 10.31%, respectively [49].

Antimicrobial effect

Water direct exposure to a magnetic field could inhibit the growth of *E. coli* [51]. Magnetized water *in vitro* was capable of decreasing *E. coli* O157:H7 and *Salmonella typhimurium* survival by 54.91% and 39.89%, respectively [49]. *In vivo* investigations revealed the inhibitory effect of magnetized water against some important pathogenic microorganisms. Broiler chickens that drank magnetized water and were challenged with *Salmonella enteritidis* showed enhanced performance, improved health and immunity, and reduced challenge organism count [50]. In addition, Soltan et al. [44] found a more significant decrease in the total intestinal bacterial count (39.3%) and coliforms count (40%), but a more remarkable increase in the lactic acid bacterial count (44.4%) and *Lactobacillus* bacteria (14.6%) in broilers treated with magnetized water compared to those of the control group. Broilers provided with magnetized water (13.200 gauss) for 6 h daily from the 5th day till the 35th day of age showed a significant reduction in the total bacterial count and total *E. coli* count in the intestinal and breast muscles which indicated the low resistance and neutralization of pathogenic microorganisms [49]. In the study of Mahmoud et al. [52], the results indicated the strong antimicrobial activity of magnetized water against gram-negative bacteria, such as *E. coli*, and beneficial effects on gram-positive ones, such as *Lactobacillus* in the gut of rabbits. Broiler chicks drank magnetized tap water, acidified water, or a combined treatment that could overcome *Salmonella enteritidis* infection hazard [50]. Moreover, the daily treatment of day-old broiler chicks with electromagnetic field-exposed water for 30 min during 35 days protected broiler chickens from *Eimeria* (*E. acervulina*), *E. maxima*, and *E. tenella* infestation, and this type of water could be considered as a possible alternative to anticoccidial medications [53].

Blood parameters

Blood parameters of poultry could be positively affected by drinking magnetized water [36]. Significant reduction in the blood levels of glucose, cholesterol, and triglycerides [54] and the elevation of protein metabolism [55] have been demonstrated in broiler chickens treated with magnetized water compared to the control birds. Similar results were obtained by Soliman et al. [49] who found that chickens supplied with magnetized water had a significant decline in glucose, creatinine, total cholesterol, triglycerides,

and ALT serum concentrations. An improvement in renal function indicated by the lower levels of urea and creatinine and an enhancement of liver function shown by the lower activity of AST and ALT enzymes have been observed in the geese supplemented with magnetized tap and well water [27].

El-Katcha et al. [48] proved that magnetized water significantly raised HDL, but reduced LDL concentrations in growing Pekin ducklings compared to those of the control group. Consequently, the reduction in serum total cholesterol, triglyceride, and LDL-cholesterol level and the increase in the HDL-cholesterol level may lead to hypotriglyceridemia, beneficial raise of "good" cholesterol, and healthier birds [56]. In rabbits, a significant reduction of creatinine and liver enzymes [57] and glutathione concentration [58] were observed after receiving magnetized water compared to the control animals. Treatment with magnetized water improved hemoglobin derivatives (methemoglobin, carboxyhemoglobin, and sulfohemoglobin), resulting in the increased non-functional hemoglobin form and enhanced overall hemoglobin level [59]. Additionally, significant increases were demonstrated in the hemoglobin level, red blood cell, white blood cell count, and packed cell volume in Japanese quails that drank magnetized water [56].

Contrary results were detected by Alhammer et al. [60] who found that the mice treated with magnetized water exhibited no effect on some liver enzymes, such as oxaloacetic transaminase, serum glutamic pyruvic transaminase, and alkaline phosphatase compared to the control non-treated group. Similarly, Mahmoud et al. [61] did not report any modification in the ALT and AST enzymes in broiler chickens after receiving magnetized water. In another study on guinea fowl, magnetized water did not affect blood potassium and chloride levels [34].

Oxidative stress

The activity of superoxide dismutase increases in the magnetic field [62]. Magnetized water could significantly influence the antioxidant capacity and reduce oxidative stress indicated by a decrease in malondialdehyde and nitric oxide levels and an increase in superoxide dismutase activity in the heart, liver, and kidney in broiler and mice trials [49, 63]. El-Katcha et al. [50] reported that broiler chicks that were infected with *Salmonella enteritidis* and received magnetized water exhibited a significant rise in the total antioxidant activity and enhanced superoxide dismutase, while at the same time, hydrogen peroxide concentration was reduced.

Furthermore, a significant reduction in lipid peroxidation markers, such as malondialdehyde and thiobarbituric acid reactive substances in male rab-

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bits treated with 4000 gauss magnetized water was reported [17]. In rats, magnetized water improved the antioxidant levels in type 2 diabetic animals [64, 65].

Conclusion

Magnetized water is one of the water treatment approaches that has attracted researchers and poultry producers owing to its low cost compared to other chemical and physical treatments of water. The use of magnetized water in the poultry production system could be regarded as an alternative strategy to improve the production traits of broilers, layers, and breeders, and enhance the carcass traits. In addition, water magnetization could improve immune response, antimicrobial activity, blood parameters, and oxidative stress. Magnetized water could be used to alleviate the harmful effects of medicines, toxins, and environmental pollutants on humans and animals. Therefore, further research in this area and encouragement of poultry farmers to treat birds with magnetized water are recommended.

Authors' Contributions

WAA collected the data and wrote and revised the manuscript.

Competing Interests

The author has no conflicts of interest to declare that are relevant to the content of this article.

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**How to cite this article**

Abd El-Ghany W. A. Magnetized Water as an Alternative Strategy to Improve the Poultry Production System. *Iran J Vet Sci Technol.* 2022; 14(3): 1-10.

DOI: <https://doi.org/10.22067/ijvst.2022.75392.1118>
https://ijvst.um.ac.ir/article_42672.html